Effect of subscapularis muscle deficiency on glenohumeral joint dynamics in anatomical and reverse total shoulder arthroplasty: A musculoskeletal simulation study

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INTRODUCTION: Total shoulder replacement (TSR) has become a well-established surgical treatment option for glenohumeral joint osteoarthritis to alleviate pain and restore shoulder function. Different implant design principles exist depending on the shoulder muscular condition, including anatomical (aTSR) and reverse total shoulder replacements (rTSR). In this context, there is no consensus on the role of the subscapularis muscle following TSR, especially in the case of rTSR [1]. However, there are few studies available that have investigated how subscapularis deficiency parameters affect the dynamics of aTSR and rTSR. Therefore, the aim of this study was to examine the biomechanical effects of the subscapularis muscle on the dynamics of the glenohumeral joint, treated with aTSR and rTSR, using a musculoskeletal multibody model of the shoulder complex.

METHODS: A previously developed kinematic model of the upper extremity [2] was used to establish a complex musculoskeletal multibody model (male, weight=58 kg) of the shoulder complex. The model was generated in the software SIMPACK™ (2022x, Dassault Systèmes) and consists of seven rigid bone geometries (thorax, clavicle, scapula, humerus, radius, ulna and hand), reconstructed from the Visible Human Male dataset [3], which were linked to a kinematic chain by idealized joints [2]. Muscle structures were included as force elements, including wrapping with segment-fixed via-points or around spherical surfaces. Commercially available implant systems, i.e., aTSR (Affinis) and rTSR (Affinis Inverse), were virtually implanted into the bone stock by supervision of an experienced surgeon. The glenohumeral joint was modeled with three rotational and three translational degrees of freedom, and a polygon contact model represents the articulating implant surfaces. The musculoskeletal model resembled the load case of an arm abduction in the scapular plane based on similar load cases from the literature [4-5]. A variant of a computed muscle control algorithm [6] utilizing static optimization was used to calculate the muscle forces from a simplified inverse dynamics model with a spherical glenohumeral joint. The muscle forces were transmitted to a forward dynamic model with a complex glenohumeral joint, i.e., six degrees of freedom including contact, to generate the predefined arm abduction motion within a forward dynamic approach. The M. subscapularis was represented by 15 muscle force elements, and deficiency was implemented by deactivating the force elements.

RESULTS: The model was validated by comparison to results of experimental studies of Ackland et al. [4-5]. Muscle and glenohumeral joint forces were estimated to evaluate the multibody simulation, showing overall good agreement. The maximum glenohumeral joint forces during the abduction movement amounted to more than 80% body weight (BW) for the aTSR and more than 45% BW for the rTSR. In case of the aTSR, a deficient subscapularis reduced the glenohumeral joint force, e.g., by 12% at 60 degree abduction (Figure 1A) in comparison to intact subscapularis, whereas for the rTSR the glenohumeral joint force was reduced by about 7% at 60 degree abduction (Figure 1B). Concerning the contact area pattern (Figure 2C-D) of the implant components, the deficient subscapularis induced a more superior translation of the prosthetic head in case of aTSR (Figure 2C). For the rTSR, almost no differences between intact and deficient M. subscapularis were observed in the contact area pattern.

DISCUSSION: The effect of a deficient subscapularis muscle on the glenohumeral joint biomechanics was characterized using a complex musculoskeletal multibody model. Deficient M. subscapularis affected the glenohumeral joint force and contact area pattern in case of aTSR, i.e., the contact area pattern moved to a more superior position. Contrarily, almost no effect of the deficient M. subscapularis was observed for rTSR regarding the contact area pattern. The presented musculoskeletal model is capable of simulating muscle and joint forces as well as glenohumeral joint movements. It can be employed to further analyze shoulder endoprosthesis designs and implant positioning as well as different muscular conditions. Future studies will be focused on evaluating the muscle moment arms and different insertion sites of M. subscapularis repair.

CLINICAL RELEVANCE: In case of aTSR, a deficient subscapularis induced a decentralization of the prosthetic head, which can lead to edge loading of the glenoid component. Therefore, a best possible repair of the M. subscapularis should be achieved. In contrast to that, the role of the subscapularis in rTSR is questionable according to our present data. From clinical side, currently several orthopaedic surgeons do not refixate the M. subscapularis in case of rTSR.

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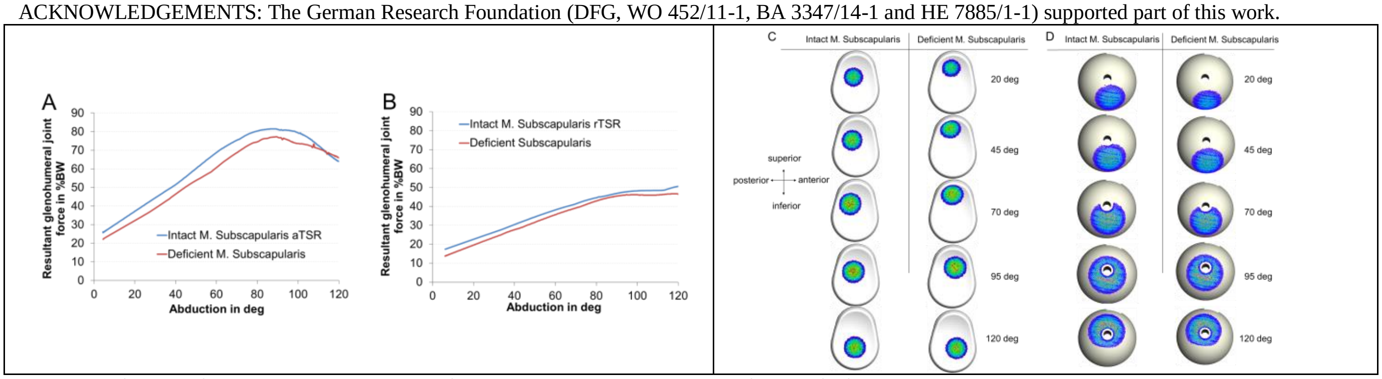

Figure 1: Influence of M. subscapularis muscle deficiency on the glenohumeral joint force (left) for aTSR (A) and rTSR (B). Contact area pattern (right) on the glenoid component for aTSR (C) and on the glenosphere for rTSR (D).